

## Floc Fraction in the Gulf of Lions

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### LONG-TERM GOALS

The goal of this research is to develop greater understanding of the dynamics of fine-grained sediment and its role in the generation of sedimentary facies on the continental shelf. In particular, we seek greater understanding of the environmental processes that influence the degree of packaging of fine-grained sediment within flocs (floc fraction), and the role of boundary shear stress in determining the change in sediment size and sorting that makes the sand-mud transition recognizable acoustically as well as lithologically.

### SCIENTIFIC OBJECTIVES

This research has three objectives:

- To determine floc fraction of sediment as it enters the coastal ocean from rivers
- To determine floc fraction of sediment in the bottom nepheloid layer
- To determine the role of floc fraction in the erosion of sediment from the seabed

### APPROACH

We pursue two basic approaches to quantifying floc fraction. The first requires co-located measurements of in situ floc size and volume concentration and total suspended particulate mass (SPM) concentration. It also requires an in situ floc size versus settling velocity relationship, which is used to convert floc volume concentration to floc mass concentration. Floc fraction is derived by dividing floc mass concentration by total SPM concentration (e.g., Curran et al., 2002a). The second method applies an inverse model of sedimentation to disaggregated inorganic grain size (DIGS) distributions in the seabed to estimate the grain size for which flux to the seabed within flocs equals the

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single-grain flux. Paired with an estimate of mean floc settling velocity, this diameter, termed the “floc limit”, can be used to calculate floc fraction in suspension (Curran et al., 2004). Our recent work in the Po delta demonstrates remarkably good agreement between these methods (Fox et al., 2004b).

An instrument called INSSECT, which stands for **I**N **S**itu **S**ize and **E**tting **C**olumn **T**ripod, was designed to determine the size and settling velocity of suspended material in situ, as well as capture flocs (Mikkelsen et al., 2004). The package includes a digital floc camera to observe the ambient floc population, a digital video camera to measure the size and settling velocity in the settling column, and a timed sediment trap consisting of 24 programmable cups containing polyacrylamide gel to collect flocs intact. Also mounted on the INSSECT are a LISST, OBS, MAVS acoustic current meter, and a compass/tilt package. INSSECT was deployed on the Po prodelta and on the Apennine Margin in February and May 2003, and in the Gulf of Lions in October 2004 and February and April 2005.

All work is being conducted collaboratively between Tim Milligan of Bedford Institute of Oceanography (BIO) and Paul Hill of Dalhousie University (Dal). Milligan takes primary responsibility for equipment design, data acquisition, and particle size analysis. Hill takes primary responsibility for modelling, data analysis, and communication of results. Danish post-doctoral fellow Ole Mikkelsen has taken primary responsibility for deployment of INSSECT and analysis and publication of results. Brent Law (BIO) and Kristian Curran (Dal) provide technical support in the laboratory and field.

## WORK COMPLETED

Our EuroSTRATAFORM fieldwork in the Adriatic is complete, and during the past year we continued data analysis and publication of results. We participated in three cruises to the Gulf of Lions in 2003 and 2004.

Our work in the Adriatic comprised four sub-projects:

1. Documentation of particle packaging in the Po River plume;
2. Interpretation of the temporal evolution of seabed DIGS on the Po prodelta;
3. Characterization of the spatial and temporal variability of floc properties in the bottom boundary layer of the western Adriatic;
4. Mapping and dynamic interpretation of the position of the sand-mud transition on the Apennine margin.

An examination of in situ fine-grained sediment packaging and its effect on sediment transport on the Po prodelta has been completed, and the results have been published (Fox et al., 2004a; Fox et al., 2004b). Fox completed his MSc thesis on this work in spring 2003.

Analysis of the evolution of the DIGS of surficial sediment since the October 2000 flood of the Po River has been completed. A manuscript describing the results is in press in the *Continental Shelf Research* special volume on Adriatic sedimentation co-edited by Tim Milligan.

Ole Mikkelsen has completed a set of papers on floc properties measured by the INSSECT in the Adriatic. All are published, in press, or accepted.

Surficial sediment samples collected off of the Tronto and Pescara Rivers have been analyzed for DIGS, sediment specific surface area, clay mineralogy, carbonate content, and metals concentrations. Doug George completed his MSc thesis on these data in late 2003, and his manuscript on this work has been accepted for publication in the Adriatic special volume.

Hill completed his “Master Volume” chapter summarizing the sediment delivery work carried out during the STRATAFORM project (Hill et al., in press).

Milligan co-edited a special volume of *Continental Shelf Research* on sedimentation in the Adriatic. Our work in the Gulf of Lions comprised two sub-projects:

1. Documentation of particle packaging in suspension at the Tet buoy site in the Gulf of Lions;
2. Documentation of the size distribution of sediment eroded from the bed as a function of shear stress.

The INSSECT was deployed successfully on three cruises in the Gulf of Lions. Kristian Curran has generated size versus settling velocity relationships for flocs observed during the cruises, and he has generated full size distributions by combining data from the digital floc camera and a LISST-100B laser particle sizer. Curran has used a Confocal Laser Scanning Microscope (CLSM) to gather images of flocs captured in polyacrylamide gels.

Brent Law has analyzed disaggregated inorganic grain size distributions during erosion of a series of cores gathered from the Gulf of Lions. Cores were collected with an hydraulically damped piston corer, then placed in Pat Wiberg’s onboard erosion chamber. The surface of each core was subjected to stepwise increases in applied shear stress. The DIGS of the initial surficial sediment was characterized, as were the DIGS of the suspended sediment at each applied stress. The DIGS of the eroded surface of the core was also measured.

## RESULTS

Investigation of particle packaging in the Po revealed that sediment is extensively flocculated, that flocs are pre-formed in the river, and that the flocculation causes rapid, proximal loss of sediment from the Po plume (Fox et al., 2004a). Comparison of suspension-based and bed-sediment-based estimates of floc fraction found good agreement (Fox et al., 2004b).

DIGS distributions have been measured at fixed depths within cores collected from 11 sites that were occupied in December 2000, June 2001, October 2001, November 2002, February 2003, and June 2003. These distributions indicate that flocculation played a bigger role in the deposition of surficial sediments on the prodelta immediately after the October 2000 flood than during later periods (Figure 1). This finding is consistent with the hypothesized positive correlation between sediment concentration and floc fraction that we proposed in our previous ONR-funded work (Curran et al., 2002b; Milligan et al., 2005, in press).

Results from the INSSECT demonstrate that size versus settling velocity relationships vary geographically and seasonally in the Adriatic and in the Gulf of Lions, but they resemble relationships gathered in a variety of other environments (Mikkelson et al., 2005a, in press). Comparison of LISST and DFC size distributions in their region of overlap indicates good agreement between size distributions. The estimated concentrations from the two instruments differ, however, by up to a factor of eight. A method for merging the size distributions has been developed (Mikkelson et al., 2005b, in press). Establishing full in situ size distributions is vital for improvement of predictions of models of optical and acoustical properties of the water column.

Mapping and interpretation of the dynamic controls on the depth of the sand-mud transition on the Apennine margin has been carried out using analysis of DIGS, sediment specific surface area, clay mineralogy, carbonate content, and metals concentrations in surficial sediment on the Pescara and Tronto shelves. This work confirms that the sand-mud transition marks an abrupt change in the flux of flocculated material to the seabed and that this change affects geochemical properties of the seabed. Dimensional analysis has been carried out using the depths of other sand-mud transitions reported in the literature. Results of this analysis suggest that except in the case of extremely high sediment concentrations, the depth of the sand mud transition is controlled by significant wave height (George et al., 2005, in press).

Images of flocs trapped in gels in the Gulf of Lions show considerable compositional variability (Figure 2). Compositional variability leads to a wide range of floc density and settling velocity for a given size, as hypothesized previously (Hill et al., 1998). Such variability needs to be considered when modeling the effect of flocs on water column optical and acoustical properties.

The grain size dependence of erosion rate differs between muddy sands and sandy muds. In muddy sands the maximum size of grains in suspension increases systematically with increasing shear stress. In sandy muds grain-size dependence of erosion rate is not evident. Therefore, mud content affects erodibility of sand.

## **IMPACT/APPLICATION**

Observations are helping to refine understanding of modes of delivery of fine-grained sediment from rivers and its incorporation into the sedimentary record. These observations suggest that the sand-mud transition, characterized by an abrupt change in sediment size and sorting, is the result of bottom stresses that scale with significant wave height. With the exception of shelves dominated by rivers with very high fine-grained sediment loads that overwhelm resuspension by wave stresses, these findings appear to be universal. Characterization of the entire particle size distribution and of floc fraction in suspension will lead to improved models of sediment transport and of the optical and acoustical properties of the water column.

## **RELATED PROJECTS**

We received funding from ONR Environmental Optics to deploy a camera at the Martha's Vineyard Cabled Observatory. The camera is co-deployed with acoustical and optical sensors (Emmanuel Boss, U. Maine) and with acoustic current meters (John Trowbridge, Woods Hole Oceanographic Institution).

The proposed parameterization of aggregation and disaggregation is being applied successfully to the interpretation of optical measurements gathered at the Coastal Mixing and Optics site by Oregon State University researchers. Collaborator is Emmanuel Boss (U.Maine)

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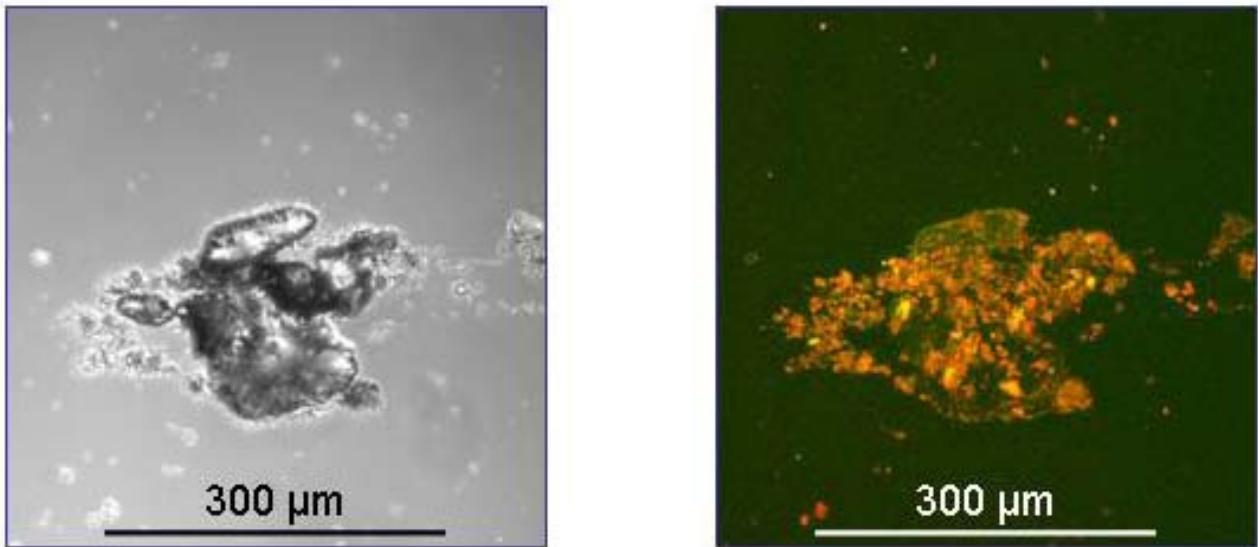
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**Figure 1.** Satellite images of the Po River plume during a flood with an overlay of floc limit of seabed sediment included in the left image. [Floc limit is large when a suspension is flocculated. The areas of high floc limit fall directly under the visible plume, indicating that during floods the sediment that is discharged is highly flocculated and deposits directly beneath the plume].



**Figure 2.** A floc imaged under transmitted and fluorescent light. [The left image taken under transmitted light reveals a mixture of mineral grains glued together by amorphous matter. The right image reveals that much of the amorphous matter fluoresces, indicating that it is fresh organic material.]